

## Cat Swarm Optimization to Shunt Capacitor Allocation in Algerian Radial Distribution Power System

Amar Hamzi, Rachide Meziane

Department of Electrical Engineering Laboratory, University of Saida, Algeria

---

### Article Info

#### Article history:

Received Mar 30, 2018

Revised May 26, 2018

Accepted Jun 26, 2018

---

#### Keyword:

Capacitor allocation

Cat swarm search

Distribution system

Optimization

---

### ABSTRACT

This paper presents a Cat Swarm Optimization (CSO) Algorithm optimization method to shunt capacitor placement on distribution systems under capacitor switching constraints. The optimum capacitor allocation solution is found for the system of feeders fed through their transformer and not for any individual feeder. The main advantages due to capacitor installation, such as capacity release and reduction of overall power and energy losses are considered. The capacitor allocation constraints due to capacitor-switching transients are taken into account. These constraints are extremely important if pole-mounted capacitors are used together with station capacitor bank. Cat Swarm search algorithm is used as an optimization tool. An illustrative example for Algerian example is presented.

Copyright © 2018 Institute of Advanced Engineering and Science.  
All rights reserved.

---

### Corresponding Author:

Amar Hamzi,

Department of Electrical Engineering,

Dr Taher Molay Saida Alger University, Algeria.

Email: hamzi32amar20@yahoo.fr

---

## 1. INTRODUCTION

Capacitors are widely used in distribution systems for reactive power compensation to achieve power and energy loss reduction, system capacity release and acceptable voltage profile. The extent of these advantages depends on the location, size, type and number of the capacitors as well as on their control settings. The capacitor allocation problem is a well-researched topic. Actually at the early stage of research, the main advantages that can be derived from applying shunt capacitors to the distribution feeders were evaluated.

The problem was solved using analytical methods for simplified models of the feeders and their load distribution [1-6]. The need to find a general solution for real distribution systems together with advances in computer technology brought to life a new generation of methods and techniques based on computer applications in [7-9]. These methods presented the annual return that can be yielded from capacitor application as an explicit function of location and size of pole-mounted capacitors. Different numerical methods were used to maximize the return and to find optimum capacitor allocation. All of the above mentioned approaches considered capacitor application to an individual feeder. In [10-13] the authors incorporated the station capacity release into their models. In [11] the losses evaluation energy in transformer station were included. It should be noted that a station capacity release and losses reduction in the transformer could not be calculated based on capacitor allocation on an individual feeder.

These values should be determined by the station capacitor bank (if any). Within the past ten years further research has taken place in the field of optimal capacitor placement in [14-15]. Load-flow on balanced or unbalanced radial feeders has been employed to evaluate the fitness of arbitrary solutions. Optimum capacitor placement has been achieved using sophisticated methods such as fuzzy logic, simulated annealing and genetic algorithms recently the cat swarm algorithm (CSO) will be applied to this problem. The above-mentioned methods have been used for capacitor allocation on an individual feeder, while only

real-power losses in the feeder are considered. These methods enable one to find the optimum capacitor allocation and control solution for an individual feeder from the viewpoint of loss reduction in the feeder. Since overall system advantages due to the capacitor application are not considered, this solution cannot be treated as an optimal one. Besides, determining capacitor placement from the standpoint of individual feeders and neglecting capacitor switching transients may lead to inserting a pole-mounted capacitor close to a station capacitor bank or to other pole-mounted capacitors. Switching a pole-mounted capacitor in the vicinity of other capacitors may subject the capacitor to extremely high inrush currents, which cause failures of capacitors and their switch-gear. The primary objective of this work is to present an ant colony approach to the problem of capacitor allocation on radial distribution feeders. Capacitor allocation is treated as a medium voltage (MT) reactive power planning procedure, while special concern is given to constraints imposed by capacitor switching transients. An ant colony algorithm is used to determine optimal placement and control of capacitors, so that the economic advantages achieved from system capacity release, overall peak load power and energy losses reduction is maximized. The rest of this paper is outlined as follows. We start in Section 2 with the problem formulation and system model description. Next, we describe the advantage of capacitor implementation in Section 3. The Capacitor allocation constraints are presented in Section 4. In Section 5, we present an illustrative example and conclusion.

## 2. R PROBLEM FORMULATION AND SYSTEM MODEL DESCRIPTION

In the general case, reactive power compensation on the medium voltage level can be achieved by the combination of a station capacitor bank on the secondary side of the station transformer with pole-mounted capacitors on the downstream distribution feeders. Main economic advantages that can be derived from medium voltage capacitor application can be summarized in [1-2] and [16] as:

- (i) Transmission and transformation kVA capacity release.
- (ii) Reduction of overall system peak-load losses.
- (ii) Reduction of annual system energy losses.

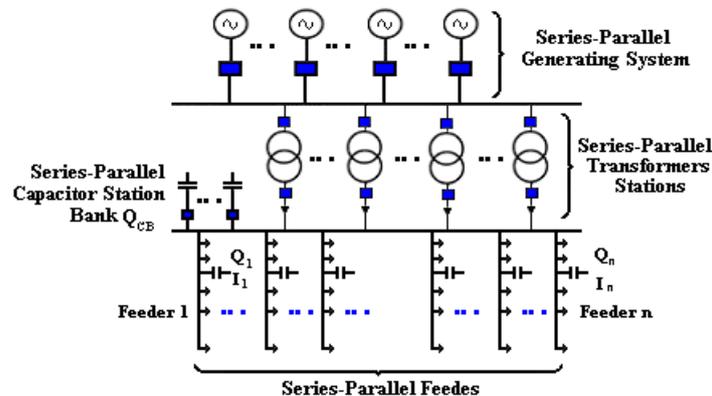


Figure 1. Series-parallel Distribution System Model for Capacitor Allocation

The system approach to optimal capacitor allocation on the distribution level is to determine kVAr ratings, placement and control settings of a station capacitor bank and of pole-mounted capacitors that maximize the above mentioned system advantages against the cost of capacitors. The optimal capacitor allocation solution shall also meet the requirements of an acceptable voltage profile along feeders in peak-load and *off-peak* states and shall conform to permissible inrush currents during capacitor switching. Optimal capacitor allocation is considered for the general series-parallel distribution system model as shown in Figure 1. Loads are supplied through radial distribution feeders fed from one of station transformers. Since parallel operation of station transformers is generally used, an equivalent scheme of power supply to some distribution system can be presented as a series connection of a transmission system, a station transformer and a network of feeders.

The transmission system is presented by a series-parallel network. The transformer model is comprised of an excitation branch and of transformer series impedance connected in series with an ideal transformer. Since most transformers are equipped with ACP, the transformation factor is assumed to be

changing with transformer loading, so as to keep constant (or load-dependent) voltage on the secondary side of the transformer. The distribution system is comprised of a network of radial distribution feeders. Each feeder includes a three-phase symmetrical main feeder and three-phase symmetrical lateral branches having any configuration, any conductor sizes and any number of distribution transformers of different kVA rating. Loads are treated as constant power sinks. Shunt capacitors are represented as susceptances, whose reactive power injection is proportional to the square of voltage at their nodes.

The advantages can be calculated based on load-flows in the considered system model. Since we are interested in thermal capacity release and peak-load loss reduction, the readings of peak-load loading of the feeders, of the feeding transformer and of the station are required. Calculation of annual energy loss reduction necessitates using Annual Load Duration Curves of the whole station and of the considered transformer. These curves are approximated by piecewise linear functions. The year is divided into  $n$  intervals during which the load profiles and load distribution between feeders are assumed to be constant as in [16-17]. We suppose that loads on each feeder vary in a conformal way proportional to annual load demand curve of the feeding transformer and to the power (current) loading of the feeder. For each load level, power flow calculations are performed to determine power losses and voltage variations along the feeders. Optimum capacitor placement on a distribution system includes optimum allocation of pole-mounted capacitors in addition to installation of a station capacitor bank on the secondary side of the feeding transformer. We assume that due to standardization, utilities generally use one or two sizes of station capacitor banks on the secondary side of a specific transformer and two or three sizes of pole-mounted capacitors. For a capacitor in specified rating station.

### 3. ADVANTAGE OF CAPACITOR IMPLEMENTATION

We consider the series-parallel distribution system as depicted in Figure 1 which has the station capacitor bank with  $Q_{CB}$  KVAR rating and  $K$  pole-mounted capacitors arbitrarily allocated on the downstream feeders. Each  $j$ -th pole-mounted capacitor is characterized by its KVAR rating  $Q_j$  belonging to a specified set of capacitor ratings, by its cost  $C_j$  and by its location  $(f_j, l_j)$ , where  $f_j$  is the number of a feeder and  $l_j$  is the number of the section on which the capacitor is installed.

#### 3.1. Advantage Of System Capacity

Unlike calculations of system capacity release in [10], [11] and [13], the proposed method takes into account parameters of the station transformer and reduction of active and reactive power losses in the distribution system and in the feeding transformer due to application of medium voltage capacitors. The primary loading of a transformer,  $S_1$  can be expressed as a function of its secondary load.

$$S_2 = P_2 + jQ_2 \quad S_1 = \frac{1}{V^2} \left[ \left( P + R_{tr} (P^2 + Q^2) \right)^2 + \left( q + X_{tr} (P^2 + Q^2) \right)^2 \right]^{\frac{1}{2}} \quad (1)$$

Where:

$$P = P_2 + P_{FE} \left( \frac{V}{V_n} \right)^2 \quad \text{And} \quad q = Q_2 + Q_{FE} \left( \frac{V}{V_n} \right)^2,$$

In Equation (1):

$R_{tr}, X_{tr}$ : The transformer series resistance and leakage reactance.

$\Delta P_{FE}, \Delta Q_{FE}$ : The no-load transformer active and reactive losses, respectively.

$V$ : The voltage maintained on the secondary side of the transformer.

$V_n$ : The rated secondary voltage of the transformer. Under the peak load conditions without reactive power compensation the transformer loading on the primary side is  $S_{1\max} = f(P_{2\max}, Q_{2\max})$ , where  $P_{2\max}$  and  $Q_{2\max}$  are the maximum active and reactive load, respectively on the secondary side. The application of the station capacitor bank and pole-mounted capacitors results in the reduction of peak-load active power losses

in the distribution system by  $\Delta P_c$  and in the total reduction of reactive power on the secondary side of the transformer by  $\Delta Q_c$ . Thus, the additional load  $g(P_{2\max}, Q_{2\max})$  can be served by the transformer without increasing its primary side loading  $S_{1\max}$ . The per-unit load increase  $g$  can be determined from the equation:

$$S_{1\max} = f((P_{2\max}(1+g) - \Delta P_c), (Q_{2\max}(1+g) - \Delta Q_c)) \quad (2)$$

The system capacity release  $SCR$  can be expressed as a function of  $g$  as follows:

$$\Delta S_{CR} = f(P_{2\max}(1+g), Q_{2\max}(1+g)) - S_{1\max} \quad (3)$$

The annual benefit due to the released system capacity is  $C_S \Delta S_{CR}$ , where  $C_S$  the cost of system thermal capacity releases.

### 3.2. Advantage Of Peack Load Loss Reduction

The cost of peak-load loss reduction  $C_{PL}$  can be represented as:

$$C_{PL} = (P_{L\max} - P_{comp}^{L\max}) c_L \quad (4)$$

Where  $P_{L\max}$  is system peak-load losses, which include losses in the distribution system, in its transformer and in the equivalent transmission system without reactive power compensation;  $P_{comp}^{L\max}$  comp is the same when the considered medium voltage capacitors are applied;  $c_L$  is annual cost of peak-load real power losses [ $\$/KW$ ] or [ $DA/KW$ ].

*One \$ Usa: Bought 100 Dinar Algerian*

### 3.3. Advantage Of Energy Loss Reduction

Annual energy loss reduction depends on control of the considered capacitors during the year. It is assumed that the station capacitor bank energization is controlled by its reactive power regulator, while the pole-mounted capacitors are switched by their time-control devices. In order to evaluate the fitness of any arbitrary solution, it is assumed that all pole-mounted capacitors are switched in conforming way at every load level. Therefore, for each load level the following possible modes of capacitors are considered:

1. All medium voltage capacitors are disconnected.
2. All pole-mounted capacitors are switched on, while a station capacitor bank is disconnected.
3. All pole-mounted capacitors as well as a station capacitor bank are in operation. The assumption of the conforming control of pole-mounted capacitors is suitable for distribution systems with conformal variations of their loads, if the time controlled capacitors of 20 KVAR ratings and higher are used. To determine the optimum capacitor control resulting in maximum energy reduction at  $i$ -th load level, total power loss reduction for all the above-mentioned modes of capacitor operation should be calculated.

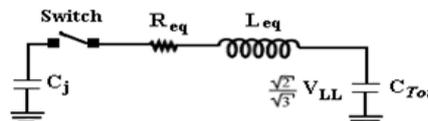


Figure 2. Equivalent Circuit for Calculating Switching Transient Capacitor System

### 3.4. Capacitor Switching Constraint

A pole-mounted capacitor shall be allocated in such a way as to prevent high inrush currents caused by its interaction with other capacitors on the distribution system. The peak value of the inrush current in pole-mounted capacitor  $j$  shall be less than the magnitude  $I_{\max_j}$  determined by the acceptable value of peak

current for its capacitors in [18] or switchgear. The  $I_2 t$  duty of a transient current in the pole-mounted capacitor due to its energization shall not exceed the maximum value maximum power loss reduction at  $i$ -th load level is determined as follows:

$$C_{PL} = c_E \times \sum_{i=1}^n \Delta P_{Li}^{max} \times T_i \quad (6)$$

Where  $c_E$  is cost of energy losses;  $T_i$  is time duration of load level  $i$ .

### 3.5. Annual return

The annual return obtained from the capacitor application  $C_{Tot}$  can be presented by Equations (4) and (6) as:

$$C_{Tot} = C_{CR} + C_{PL} + C_{EL} + C_{CB} - \sum_{j=1}^k C_j \quad (7)$$

Where  $C_{CB}$  the annual cost of the station capacitor bank;  $C_j$  capacitor  $j$ . The main system advantages due to capacitors' application, as was shown above, depend on KVAR ratings  $Q_j$ , location  $l_j$  and control of the pole-mounted capacitors. So, if the MVAR of the station capacitor bank is specified, the optimal allocation and control of pole-mounted capacitors can achieve the maximum return.

## 4. CAPACITOR ALLOCATION CONSTRAINTS

Determining sizes and locations of pole-mounted capacitors requires taking into account constraints imposed by voltage variation at the load nodes and by capacitor switching transients.

### 4.1. Voltage Constraint

The voltage constraints can be taken into account by specifying upper and lower limits of voltage variation at the nodes of the distribution system [16-17]. For every node  $m$  in the distribution system at every load level  $i$ , these constraints can be expressed as

$$V_{min}^2 \leq V_{mi}^2 \leq V_{max}^2, m = 1, \dots, M, i = 1, \dots, n \quad (8)$$

Where  $m$  the total number of nodes in the distribution system.

## 5. ADVANTAGE OF SYSTEM CAPACITY

A pole-mounted capacitor shall be allocated in such a way as to prevent high inrush currents caused by its interaction with other capacitors on the distribution system. The peak value of the inrush current in pole-mounted capacitor  $j$  shall be less than the magnitude  $I_{max j}$  determined by the acceptable value of peak current for its capacitors [18] or switchgear. The  $I^2(t)$  duty of a transient current in the pole-mounted capacitor due to its energization shall not exceed the maximum value  $I^2(t_{max})$  that the fuses can withstand without spurious melting [17].

In general, determining the transient switching current of a capacitor energized in a distribution system which contains other capacitors requires use of the Electromagnetic Transient Program [19]. To impose the current switching constraints on capacitor allocation, we propose a simplified analytical method to determine the peak switching current and its  $I_2(t)$  value. This method is based on the assumption that during switching of a capacitor all other capacitors already considered as a single capacitor in [19]. Therefore, the capacitances of the already switched capacitors can be lumped together. The switching current of pole-mounted capacitor, due to its interaction with other capacitors, can be calculated using the equivalent circuit of capacitor back-to-back switching in [20] refer to Figure 2. Back-to-back switching current  $I_{sw}(t)$ ,

which results from switching a capacitor with capacitance  $C_j$  against the equivalent system capacitor with capacitance  $C_{Tot}$ , can be expressed as:

$$\begin{cases} I_{SW}(t) = \frac{\sqrt{2}}{\sqrt{3}} \cdot V_{LL} \times \sqrt{\frac{C_{eq}}{L_{eq}}} \cdot e^{-\frac{R_{eq}}{L_{eq}} t} \cdot \sin \frac{1}{\sqrt{L_{eq} \times C_{eq}}} t \\ IF \frac{L_{eq}}{C_{eq}} \geq \frac{R_{eq}^2}{4} \end{cases} \quad (9)$$

Where  $C_{eq} = \frac{c_j \cdot C_{Tot} C_{eq}}{C_j + C_{Tot}}$  is equivalent capacitance of the circuit;  $R_{eq}$  and  $L_{eq}$  are alternating current resistance and inductance, respectively, between the capacitor being energized and the capacitor already energized;  $V_{LL}$  is phase-to-phase maximum system voltage. The peak value of the inrush current  $I_{SW \max}$  and its  $I^2(t)$  value can be expressed in terms of rated reactive power of the considered capacitor  $Q_j$ , rated reactive power of the corresponding equivalent system capacitor  $Q_{tot}$  and their mutual impedance:

$$\begin{cases} I_{SW \max j} = \frac{\sqrt{2}}{\sqrt{3}} \cdot V_{LL} \cdot \sqrt{\frac{C_{eq}}{L_{eq}}} = \sqrt{\frac{2}{3} \cdot \frac{Q_j \cdot Q_{tot}}{(Q_j + Q_{tot}) X_{eq}}} \\ I^2 t_j = \int_0^{\infty} I_{SW}^2(t) dt = \frac{Q_j \cdot Q_{tot}}{3 \cdot (Q_j + Q_{tot}) R_{eq} \cdot \omega} \end{cases} \quad (10)$$

Where  $X_{eq} = \omega \cdot L_{eq}$  the equivalent reactance between the capacitors and  $V$  the fundamental angular frequency. Therefore, the capacitor switching constraints imposed on the allocation of pole-mounted capacitor  $j$  can be presented as

$$I_{SW \max j} \leq I_{\max j} I^2 t_{S \max j} \leq I^2 t_{\max j} \quad (11)$$

Imposing the switching constraints on allocation of every pole-mounted capacitor requires calculation of parameters of the equivalent circuit of its switching:  $Q_{tot}$ ,  $R_{eq}$ ,  $X_{eq}$ . The calculation of the above parameters is achieved by circuit reduction with reference to the node of the considered pole-mounted capacitor. The station capacitor bank presents an equivalent capacitor on the station bus bars. This capacitor in its turn is paralleled with other capacitors on the feeder, where the considered capacitor is installed. Paralleling branches with capacitors implies lumping together their capacitances along with connecting their impedances in parallel.

## 6. THE CAT SWARM SEARCH ALGORITHM

The problem formulated in this paper is a complicated combinatorial optimization problem. The total number of different solutions to be examined is very large, even for rather small problems. An exhaustive examination of the enormous number of possible solutions is not realistic, considering time limitation. The total number of different solutions to be examined is very large, even for rather small problems. Thus, because of the search space size of the reliability optimization for MSS, a new meta-heuristic is developed in this section. This meta-heuristic consists in an adaptation of the Cat Swarm search algorithm (CSO) optimization method to this specific problem.

### 6.1. The CSO Overview

Optimization is prevalent in almost all field of science and engineering. In recent years several optimization methods are proposed and used such as Swarm Optimization Algorithm (CSO). Chu et al.[21] divided CSO algorithm into two sub-models based on two of the major behavioural traits of cats. These are termed seeking mode" and tracing mode". In CSO, we first decide how many cats we would like to use in the

iteration, then we apply the cats into CSO to solve the problems. Every cat has its own position composed of dimensions, velocities for each dimension, a fitness value, which represents the accommodation of the cat to the fitness function, and a flag to identify whether the cat is in seeking mode or tracing mode. The final solution would be the best position of one of the cats. The CSO keeps the best solution until it reaches the end of the iterations [22].

When applying the CSO algorithm to solve optimization problems, the initial step is to make a decision on the number of individuals or cats to use. Each cat in the population has the following attributes: 1) a position made up of M dimensions; 2) velocities for each dimension in the position; 3) a fitness value of the cat according to the fitness function; and; 4) a flag to indicate whether the cat is in seeking mode or tracing mode. The CSO algorithm keeps the best solution after each cycle and when the termination condition is satisfied, the final solution is the best position of one of the cats in the population. CSO has two sub-modes, namely seeking mode and tracing mode and the mixture ratio MR dictates the joining of seeking mode with tracing mode. To ensure that the cats spend most of their time resting and observing their environment, the MR is initialized with a small value. The CSO algorithm can be described in 6 steps as presented in [7][9].

**Step 1.** Create N cats in the process.

**Step 2.** Randomly sprinkle the cats into the M-dimensional solution space and randomly give values, which are in-range of the maximum velocity, to the velocities of every cat. Then haphazardly pick number of cats and set them into tracing mode according to MR, and the others set into seeking mode.

**Step 3.** Evaluate the fitness value of each cat by applying the positions of cats into the fitness function, which represents the criteria of our goal, and keep the best cat into memory. Note that we only need to remember the position of the best cat ( $x_{best}$ ) because it represents the best solution so far.

**Step 4.** Move the cats according to their flags, if  $cat_k$  is in seeking mode, apply the cat to the seeking mode process, and otherwise apply it to the tracing mode process.

**Step 5.** Re-pick number of cats and set them into tracing mode according to MR, then set the other cats into seeking mode.

**Step 6.** Check the termination condition, if satisfied, terminate the program, and otherwise repeat Step 3 to Step 5

## 7. The GSA Principle

Basic flowchart diagram for CSO algorithm show in Figure 3.

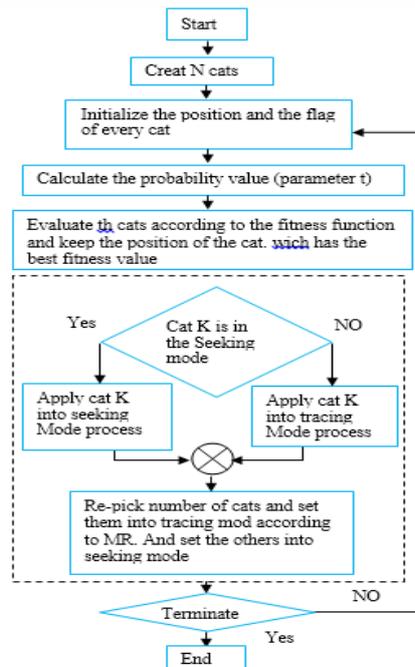


Figure 3. Basic Flowchart Diagram for CSO Algorithm

## 8. ILLUSTRATIVE EXAMPLE

The cat swarm search algorithm program developed on the base of the proposed new meta-heuristic algorithm has been successfully used for optimal allocation of about 25 pole-mounted capacitors in 09 distribution systems of *Algerian Company of Electricity and Gaz (EGA)*. The optimum capacitor allocation and control have been determined for real distribution system models including 50 of loads supplied through radial distribution feeders of real configuration. The real *ALDC* of the step-down transformers have been used. In order to give clear illustration of the proposed method consider optimal capacitor allocation on the simplified distribution system fed by the 90/30 KV and 3\*30 MVA station transformer see Figure 3. The transformer is installed on a station with three uniformly loaded transformers. Loading of each transformer in peak-load condition is  $S_{1max} = 32.5 MW + j17.9 MVAR$ , i.e. 80% of the transformer MVA rating. According to EGA reliability requirements to power supply, the peak-load loading of a transformer on a three-transformer substation shall not exceed 85% of the transformer MVA rating. Therefore, the further station load growth will require construction of an additional transformer substation and of HT transmission lines to connect it to the system grid. The construction of a new substation can be deferred by applying medium voltage power capacitors. Types of 30 kV capacitors to be used for reactive power compensation and their annual costs are listed in Table 1. It is assumed that the both transformers have similar *ALDC* presented as the following function of time  $t$ :

$$AC(t) = 1 - 0.34t + 0.154043t^2 - 0.03635t^3 + \dots + t^5$$

The year is divided into 20 equal intervals. Apparent power on the primary side of the considered transformer during interval  $i$   $S_{1i}$  is assumed to be constant and is expressed as:

$$S_{1i} = 0.5 \cdot S_{1max} (AC(t_{ib}) + AC(t_{ie}))$$

Where  $t_{ib}$  and  $t_{ie}$  are the beginning and the end of the interval  $i$ . The distribution network considered is presented in Figure 3. It is assumed that the load is uniformly distributed between four feeders. To simplify system description and at the same time some general regularity in capacitor allocation, each feeder is presented as the combination of uniformly distributed load with end concentrated load. Each feeder includes 50 load nodes separated from each other by uniform feeder sections of 200 m and total length of each feeder is 17 km. Specific impedance of the feeders is  $Z_0 = 0.22 - j0.34 \Omega.km$ . The considered transformers have the following parameters:

- $R_{tr} = 0.0046 PU$
- $X_{tr} = 0.1842 PU$
- $\Delta P_{FE} = 29.3 kW$
- $\Delta Q_{FE} = 42.3 kVAR$

The voltage regulator changes the transformation factor with the load variation so as to keep secondary voltage  $V_2 =_{+}^{-} 23.6 kV$ .

Equivalent system resistance of the transmission system is:  $R_{sys} = 2.63 \Omega$  corresponding to 90 kV.

The annual system costs are:

- $c_{CR} = 28.5 \quad \$/kW$
- $c_L = 42.6 \quad \$/kW$
- $c_E = 0.03 \quad \$/kWh$

First, optimal capacitor allocation was determined regardless of the capacitor switching constraints. The optimum solution includes *five* pole-mounted capacitors of 1800 KVAR rating to be installed in addition to the station capacitor bank:

- Four pole-mounted capacitors are uniformly divided among the feeders, so that each capacitor is connected to load bus 50 of the corresponding feeder 09,6 km from the station

- One pole-mounted capacitor is connected to the station bus-bars in parallel to the substation capacitor bank. Switching of the latter pole-mounted capacitor against the station capacitor bank already energized will cause failures of its capacitors together with spurious melting of its fuses.

To determine optimal capacitor allocation with regard to the capacitor switching constraints, the acceptable values of the pole-mounted capacitors  $I_{max}$  and  $I_2(t_{max})$  were calculated among the Table 1. The optimum capacitor allocation solution includes five pole-mounted capacitors of 20 KVAR rating to be installed in addition to the substation capacitor bank as shown in Figure 3. Like in the previous solution, four pole mounted capacitors are connected to 50 load busses of the corresponding feeders. An additional capacitor is connected to load bus five of the first feeder. To maximize energy loss reduction, the pole-mounted capacitors shall be in operation throughout the year, while the station bank shall be energized only 8760 h in the year. The results of capacitor allocation can be explained as follows:

Placement of 20 kVAr capacitors at bus 50 of the considered feeders provides maximum peak power and energy loss reduction in the feeders. On the other hand, system thermal capacity releases peak-power and energy loss reduction in the feeders. Maximum system benefits are yielded if the station capacitor bank and additional 16 KVAR capacitor are placed at the station bus-bars. In order to comply with the capacitor switching constraints, some impedance shall be inserted between the capacitor bank and the pole-mounted capacitor. Placing the capacitor on one of the feeders at 1 km from the station bus-bars. The effectiveness of the capacitor allocation solution presented in Figure 3 is shown in Table 2.

**8.1. Description if the System to be Optimized**

The electrical power station system with optimal shunt capacitor allocation which supplies the consumers is designed with 3 basic sub-systems. The detailed process of the electrical power system (production system, transformers system and MT feeders distribution). The process of electrical power system is described as follows: The electrical power is generated from the station generators (sub-system 1). Then transformed for medium voltage (MT) by the MT transformers (sub-system 2) and distributed by MT feeders (sub-system 3) which supplies the MT load. A bank of compensation capacitors will be installed in the medium bus and on feeders.

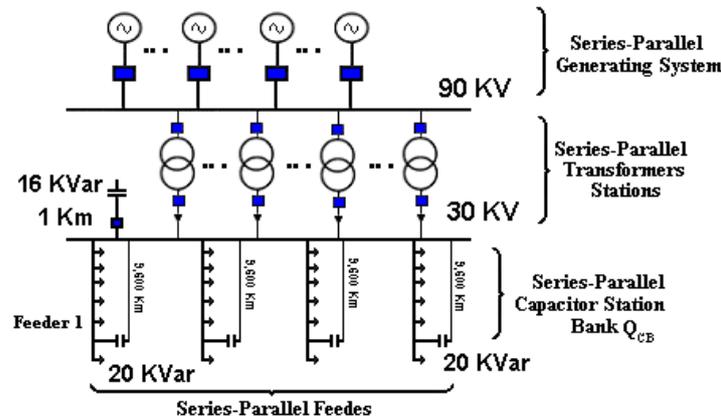


Figure 4. Optimal Capacitors Allocation

**8.2. Optimal solution given by the Cat Swarm search algorithm**

Parameters of Annual Load Demand Curve and Optimal Solution of General System is shown in Table 1 and 2.

Table 1. Parameters of Annual LoadDemand Curve

# Of Load	50 Bus_Bar
Demand (%)	98 %
Duration (h)	6780

Table 2. Optimal Solution of General System

Item	Amount	Annual Cost M.DA
System Capacity Release	8 MVA	0.855.000
Peak-Load Loss Reduction In System	100 kW	0.520600
Capacity Cost		1.622000
Annual Save		10.067000

## 9. CONCLUSION

The program developed in this paper is based on the proposed algorithm has been successfully used for optimal shunt capacitor allocation of about 25 pole-mounted capacitors in 09 distribution systems of west Algerian Network. The optimum capacitor allocation and control have been determined for real distribution system models including 50 of loads supplied through radial distribution feeders of optimal configuration. In order to give clear illustration of the proposed method considers optimal capacitor allocation on the simplified distribution system fed by the 90/30 kV station transformer shows the parameter of annual load demand curve.

The method can reduce the peak load loss in the system, capacity cost and a considerable annual save will be obtained. In the description by applying the cat swarm search algorithm, we determine the optimal allocation capacitor downstream of the transformers and in feeders. The program is done in Java and the time to find the optimal solution is about 2 mn.

## REFERENCES

- [1] R. F. Cook, "Analysis of capacitor application as affected by load cycle," *AIEE Trans.*, Vol. 3, 1959, pp. 950-957.
- [2] R. F. Cook, "Optimizing the application of shunt capacitors for reactive-volt ampère control and loss reduction," *AIEE Trans.*, Vol. 3, pp. 430-444.
- [3] W. U. Baum, W. A. Frederik, "A method of applying switched and fixed capacitors for voltage control," *IEEE, Trans. Power Appar. Syst.* PAS-84, no. 1, 1965, pp. 42-48.
- [4] J. V. Schmill, "Optimum size and location of shunt capacitor on distribution," *IEEE Trans. Power Appar. Syst.* , PAS-84, no. 9, 1965, pp. 825-832.
- [5] N. E. Chang, "Generalized equations on loss reduction with shunt capacitor," *IEEE Trans. Power Appar. Syst.* PAS-91, no. 5, 1972, pp. 2189-2195.
- [6] Y. G. Bae, "Analytical method of capacitor allocation on distribution primary feeders," *IEEE Trans. Power Appar. Syst.* PAS-97, Vol. 4, 1972, pp. 1232-1238.
- [7] H. Duran, "Optimum number location and size shunt capacitors in radial distribution feeders a dynamic programming approach," *IEEE Trans. Power Appar. Syst.*, PAS-87, Vol. 9, 1968, pp. 1769-1773.
- [8] J. J. Grainger, S. H. Lee, "Optimum size and location of shunt capacitors for loss reduction of losses on distribution feeders," *IEEE Trans. Power Appar. Syst.* PAS-100, Vol. 3, 1981, pp. 1105-1118.
- [9] J. J. Grainger, S. H. Lee, "Capacity release by capacitor placement on distribution feeders: a new volatge dependent," *IEEE Trans. Power Appar. Syst.* PAS-101, Vol. 5, 1982, pp. 1231-1244.
- [10] T. H. Fawzi, S. M. El-Sokbi, M. A. Abdel-Halim, "New approach for the application of shunt capacitors to the primary feeders," *IEEE Trans. Power Appar. Syst.* PAS-102, Vol. 1, 1983, pp. 10-13.
- [11] M. Ponnaivaikko, K. S. Prakasa Rao, "Optimal choice of fixed and switched shunt capacitors on radial distributors by the method of local variations," *IEEE Trans. Power Appar. Syst.* PAS-102, Vol. 6, 1983, pp. 1607-1615.
- [12] J. J. Grainger, S. Civanlar, K. N. Clinard, L. J. Gale, "Discrete-tap control scheme for capacitive compensation of distribution feeders," *IEEE Trans. Power Appar. Syst.* PAS-103, Vol. 8, 1984, pp. 2098-2107.
- [13] M. Kaplan, "Optimization of number location size control type and control settings of shunt capacitors on radial distribution feeders," *IEEE*.
- [14] G. Levitin, A. Lisnianski, H. Ben-Haim and D. Elmakhias, "Redundancy optimization for series-parallel multi-state systems," *IEEE Trans. On Reliability*, Vol. 47 no. 2, 1998, pp. 165-172.
- [15] A. Lisnianski, G. Levitin, H. Ben-Haim and D. Elmakhias, "Power system structure optimization subject to reliability constraints," *Electric Power System Research*, Vol. 50, 1999, pp. 183-190.
- [16] R. Billinton and R. Allan, *Reliability evaluation of power system*, Pitman, 1990.
- [17] I. A. Ushakov, G. Levitin and A. Lisnianski, "Multi-state system reliability: from theory to practice," in: proceeding of third international conference on mathematical methods in reliability, Trondheim: Norway, 2002, pp. 68-73.
- [18] G. Levitin, A. Lisnianski, "A new approach to solving problems of multi-state system reliability optimization," *Quality and reliability engineering international*, 47(2), 2001, pp. 93-104.
- [19] M. S. Chern, "On the computational complexity of reliability redundancy allocation in series systems," *Operational research letter*, 11, 1992, pp. 93-104.
- [20] F. C. Tillman and W. Kuo, "Optimization techniques for reliability with redundancy a review," *IEEE Transaction on Reliability*, Vol. 26, no. 3, 1997, pp. 148-155.
- [21] Chu, S.C., Tsai, P.W., Pan, J.S.: Cat swarm optimization. In: Yang, Q., Webb, G. (eds.) PRICAI 2006. LNCS (LNAD), vol. 4099, pp. 854-858. Springer, Heidelberg (2006).
- [22] Santosa, B., Ningrum, M.: *Cat Swarm Optimization for Clustering*. In: International Conference of Soft Computing and Pattern Recognition, pp. 54-59 (2009).
- [23] Shi, Y., Eberhart, R.: *Empirical study of particle swarm optimization*. In: Congress on Evolutionary Computation, pp. 1945-1950 (1999).